N91-10321

STRUCTURAL RISK ASSESSMENT AND AIRCRAFT FLEET MAINTENANCE

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WEIBULL STATISTICAL ANALYSIS OF FIELD INSPECTION AND AIRCRAFT USAGE DATA HAS BEEN USED TO PREDICT THE RISK OF STRUCTURAL FAILURE

We have described in previous work (ref. 1 and 2) the use of damage tolerance analysis and Weibull statistical analysis in the assessment of structural risk. The interference of the failure distribution and the aircraft life distribution is computed to determine the risk of structural failure. Information from any number of aircraft from different bases can be combined to give a projection of the risk associated with continued operation at the same or modified usage levels.

Three parameter Weibull distributions are determined from the flight usage data and the failure information obtained from field inspection of the aircraft. In the present analysis, deterministic flaw growth analysis is used to project the failure distributions from inspection data.

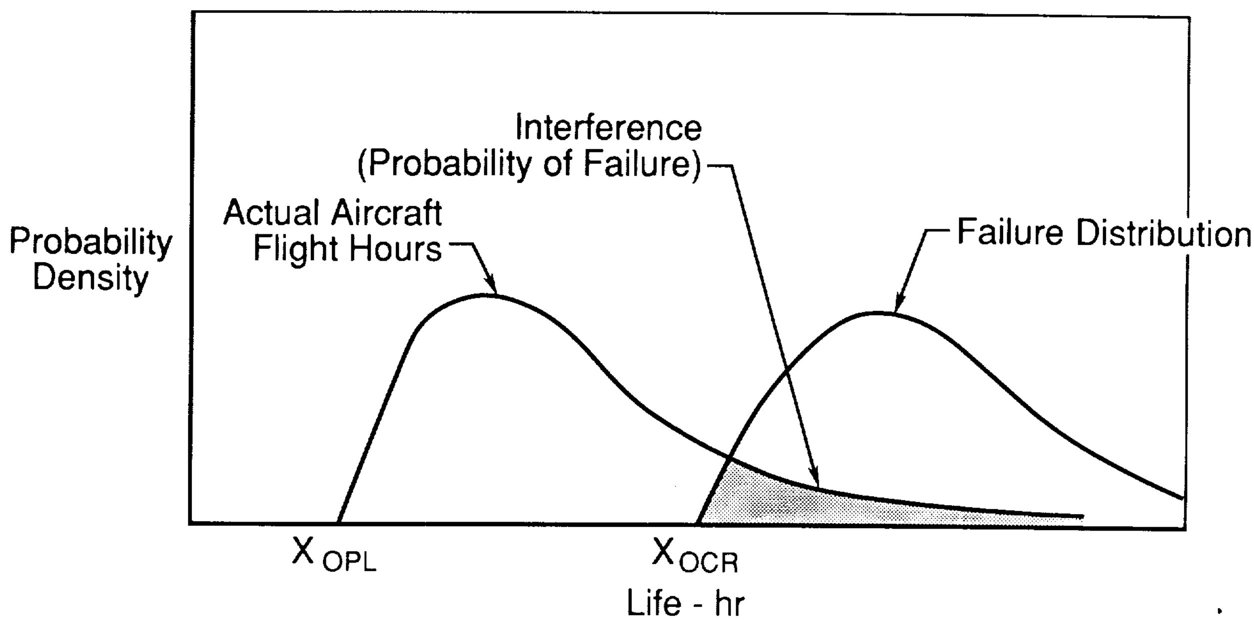

Figure 1

DETERMINATION OF FAILURE DISTRIBUTION FROM FIELD SERVICE INSPECTION DATA

Inspection data is reported for each critical point in the aircraft. The data will indicate either a crack of a specific size or no crack. The crack length may be either less than, equal to, or greater than critical size for that location.

Non-critical length cracks are projected to failure using the crack growth characteristics for that location to find the life when it will be at critical length. Greater-than-critical length cracks are projected back to determine the life at failure, that is, when it was at critical length. The same process is used as in the case of a non-critical crack except that the projection goes the other direction. These points, along with the critical length cracks are used to determine the failure distribution.

To be able to use data from different aircraft to build a common failure distribution, a consistent life variable must be used. Aircraft life varies with the severity of the usage, therefore the number of flight hours for a particular aircraft must be modified by its usage factor to obtain a normalized life which can be compared with that from other aircraft.

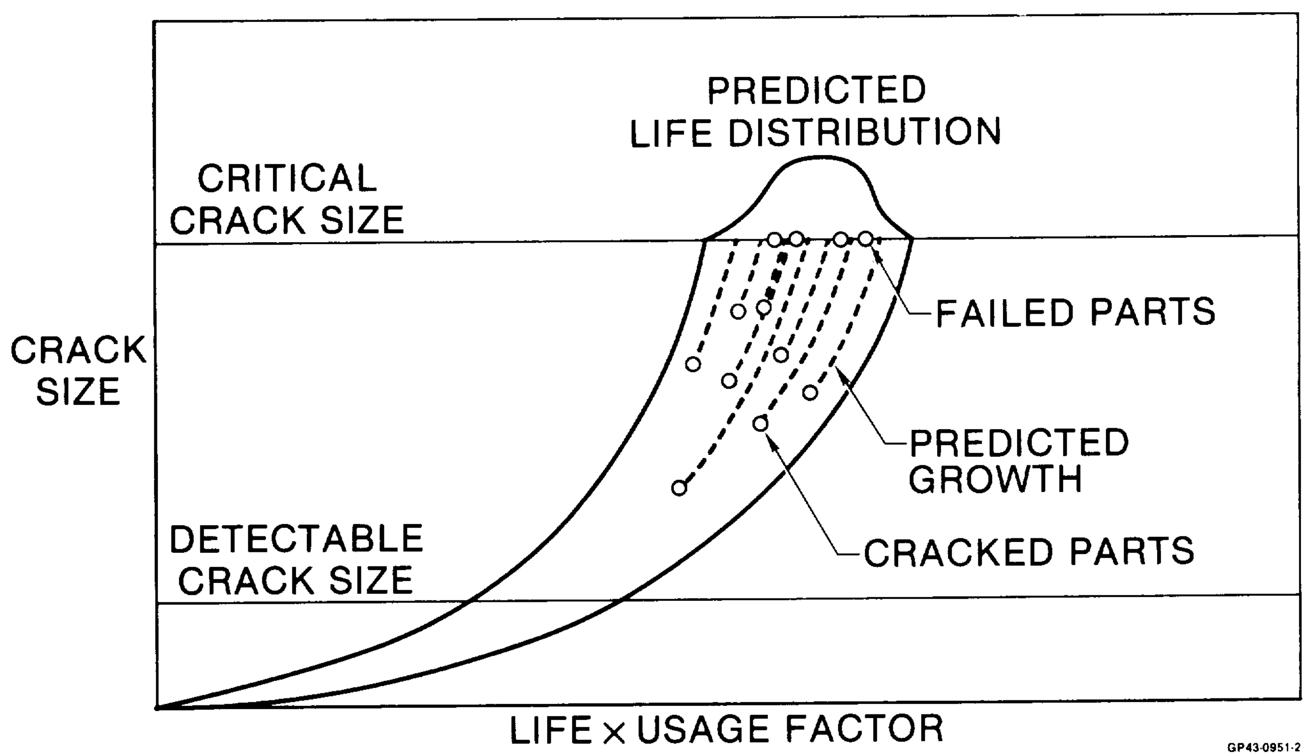

Figure 2

USAGE FACTOR ALLOWS THE COMPARISON OF DATA FROM DIFFERENT AIRCRAFT

The aircraft is designed to a baseline or design spectrum. This is determined from the design mission requirements for the aircraft. The actual usage of the aircraft will vary greatly depending upon where the aircraft is based when it enters service. Some bases fly many more benign flights and others fly more severe flights than the baseline. For flight hours to be compared from one aircraft to another, they must be related to the same severity level or no direct comparison is possible. The usage factor is used to adjust the actual number of flight hours for the difference between the baseline usage and the actual usage of the aircraft. This method has been shown (ref. 3) to accurately account for the effect that usage has on the crack growth characteristics. The usage factor is the ratio of the projected life of the aircraft for the present usage to the baseline life.

$$UF_s = \frac{L_b}{L_s} (> 1.0) \qquad UF_m = \frac{L_b}{L_m} (< 1.0)$$

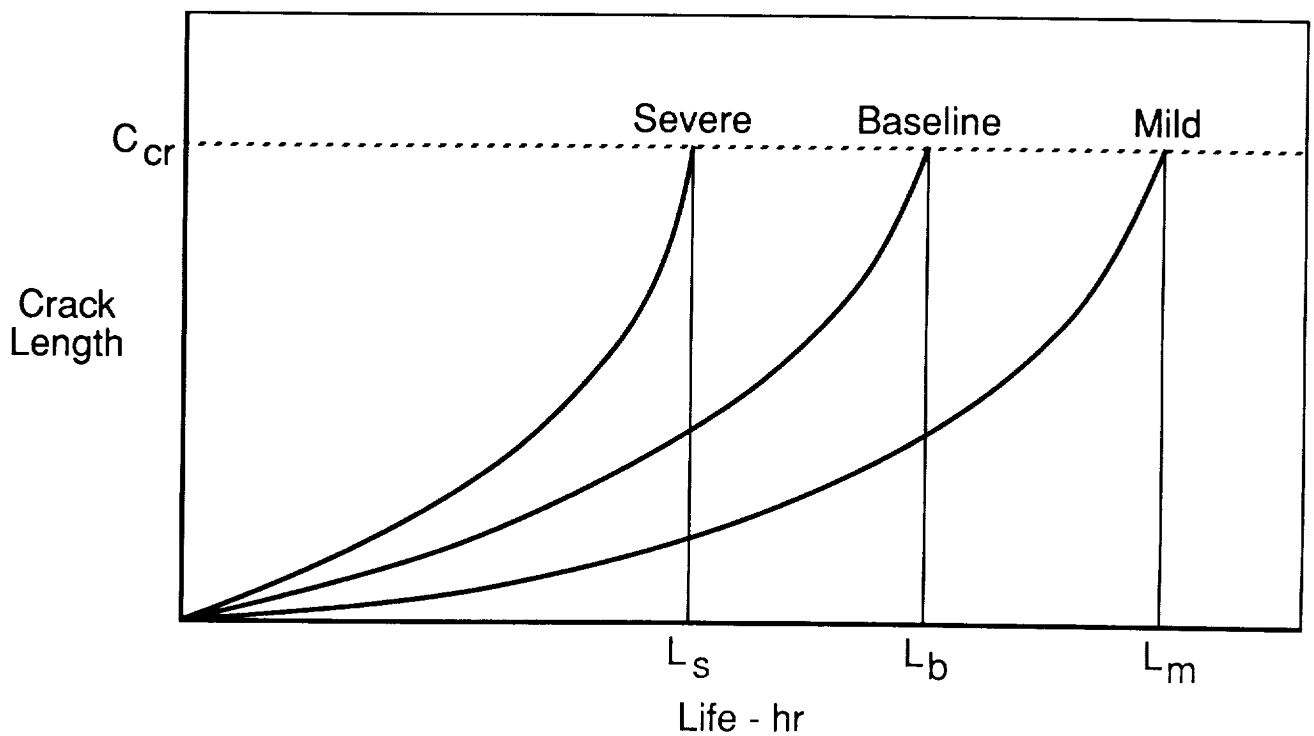

Figure 3

FIELD DATA IS USED TO DETERMINE THE THREE-PARAMETER WEIBULL DISTRIBUTION

Data from field inspections are used to determine the failure and life characteristics of the aircraft under consideration. The distribution of current lives is found from the number of hours (adjusted by usage) recorded for each aircraft. The failure distribution is found from the set of lives associated with the critical crack lengths. Again, the lives must be adjusted for the difference in usage.

Linear regression is used to determine the best 3-parameter Weibull fit to the data. The median ranks are determined for the failed points and take into account the effects of the suspended items (non-cracked aircraft) on the rank values. The minimum expected life is found from a search process which determines what minimum life value gives the best straight line fit to the data.

The difficulty with this process is twofold. First, there are generally only a few cracked parts from which you want to construct the failure distribution. The accuracy of the distribution so computed can be questioned. Second, the growing, or projecting, process assumes that the crack growth characteristics are deterministic.

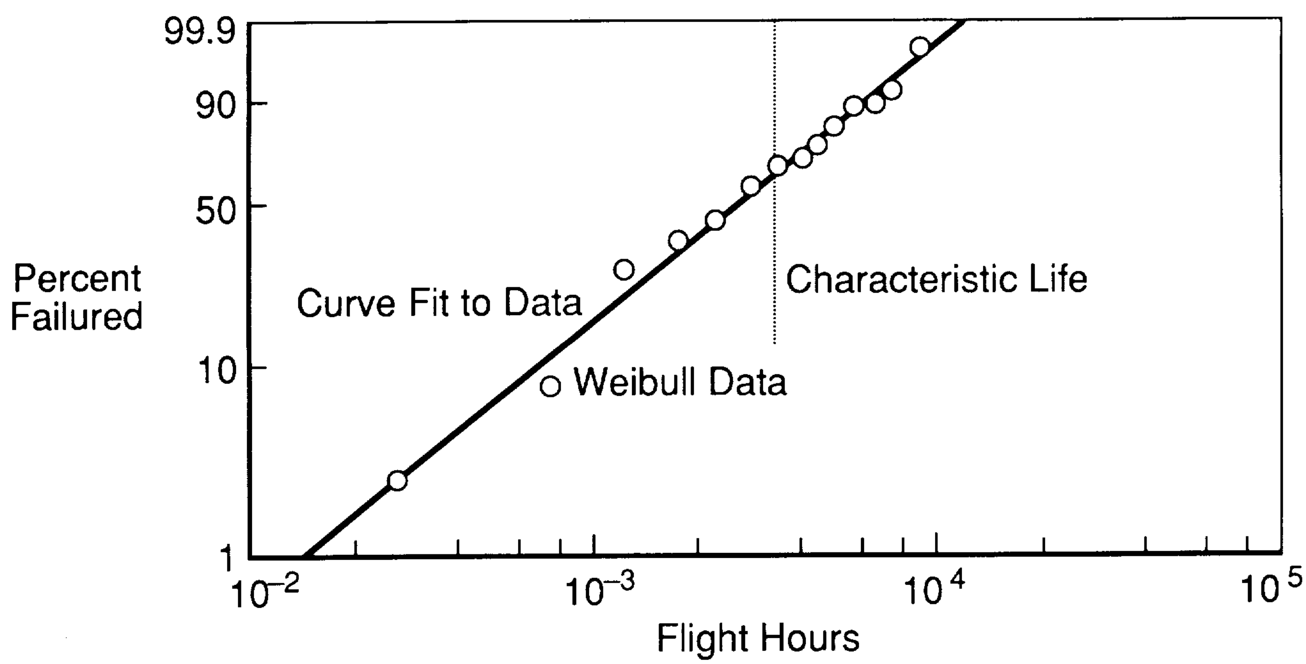

Figure 4

MULTIPLE FAILURE MODES ARE SOMETIMES PRESENT

Failures will sometimes result from several phenomenon. Manufacturing or material defects can precipitate early failures. These will generally occur well before the normal service failures. These failures are of interest, but it is important to separate this behavior from the normal service behavior for fleet management purposes. In addition, it is improper to attempt to fit a Weibull distribution to the combined data set since it does not correctly characterize either behavior pattern. The data set must be pruned to include only the long-term effects of the normal service life if an accurate picture of the failure rate and risk are desired. Generally the bulk of the data will be in this set, with the early failures being few in number.

Similarily, if one wants to concentrate on short-term failures, the data must be pruned of other failure modes. Plotting all data, as shown in this chart, can help identify when more than one failure is represented in the data.

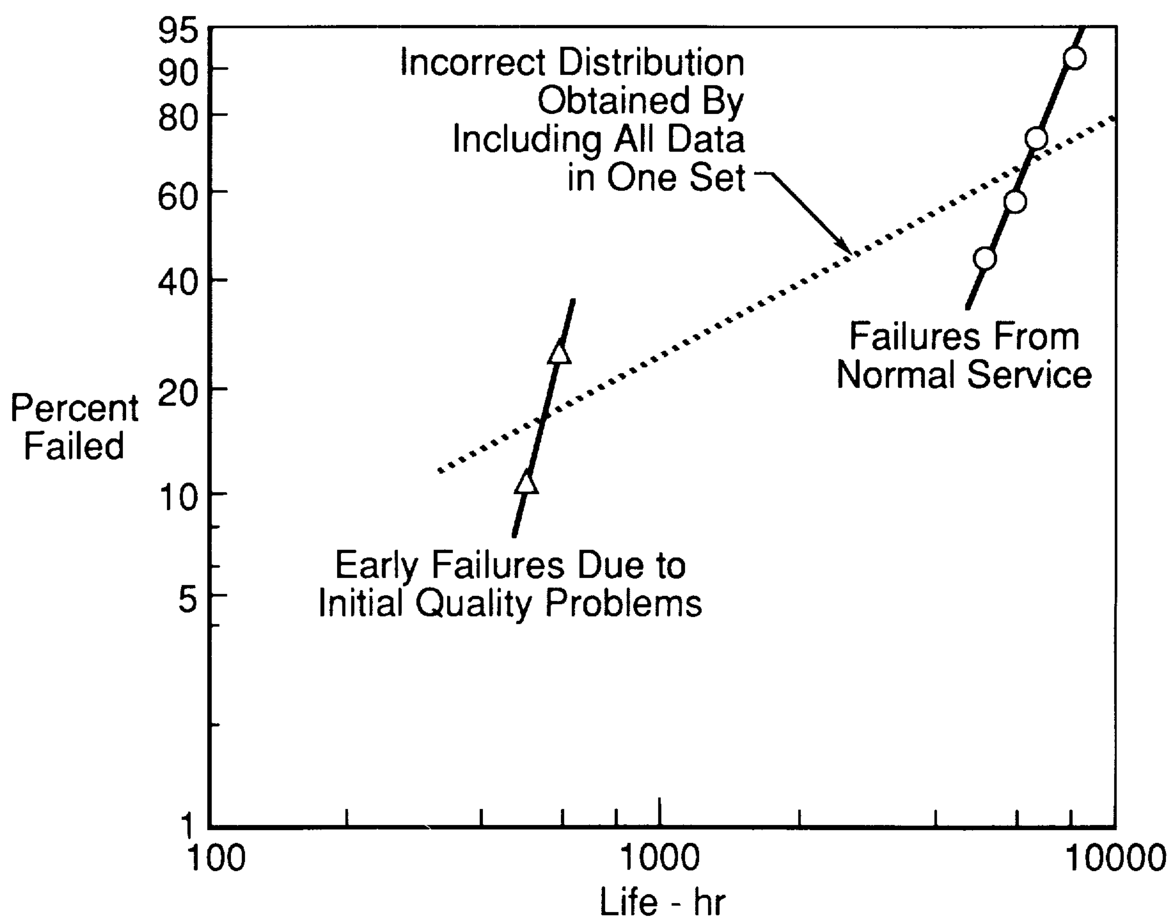

Figure 5

INITIAL INSPECTION DATA FOR 158 AIRCRAFT SHOWS 6 FAILURES

Inspection of 158 fighter aircraft revealed the existence of 6 aircraft with cracks of critical length at a point of concern on the vertical tail. Computation of the Weibull distribution shows that the data fits the curve fairly well, exhibiting a 0.97 correlation coefficient.

Closer examination of the data points indicates that perhaps there are two failure modes present. The first failure at 770 hours seems to be isolated from the remaining five points.

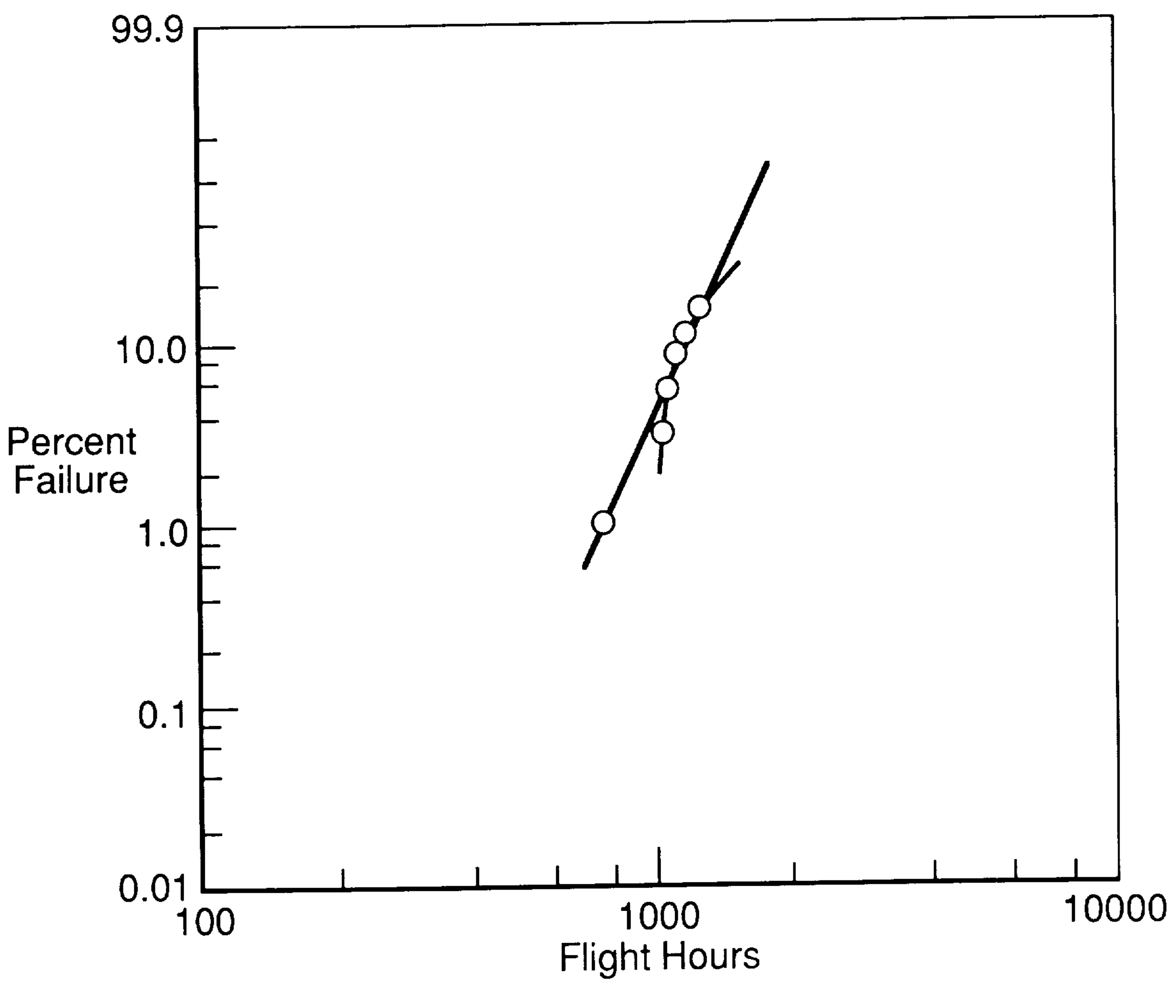

Figure 6

CUMULATIVE PROBABILITY OF FAILURE FOR ORIGINAL DATA

The cumulative probability of failure for the original data set containing six failures is shown. Included on the plot is the 90% confidence band. The confidence band is very important to the decision making process since frequently (as in this case) there are only a few failures from which the fleet commander must reach a decision.

The confidence bands were computed using two different methods. The five and ninety five percent ranks were computed and fit with a Weibull distribution along with the median ranks. This method provides the range for all three Weibull parameters; however, the computation of the ranks and the curve-fitting procedure result in a substantial computation time. The second method utilized the t distribution to compute the confidence band for the linear regression parameters for the curvefit to the median ranks. This process is much faster; however, we obtain no information for the Weibull location parameter. This is a significant loss because the location parameter represents the failure free operating period. The ability to rapidly generate confidence limits for the available data is felt to outweigh this loss.

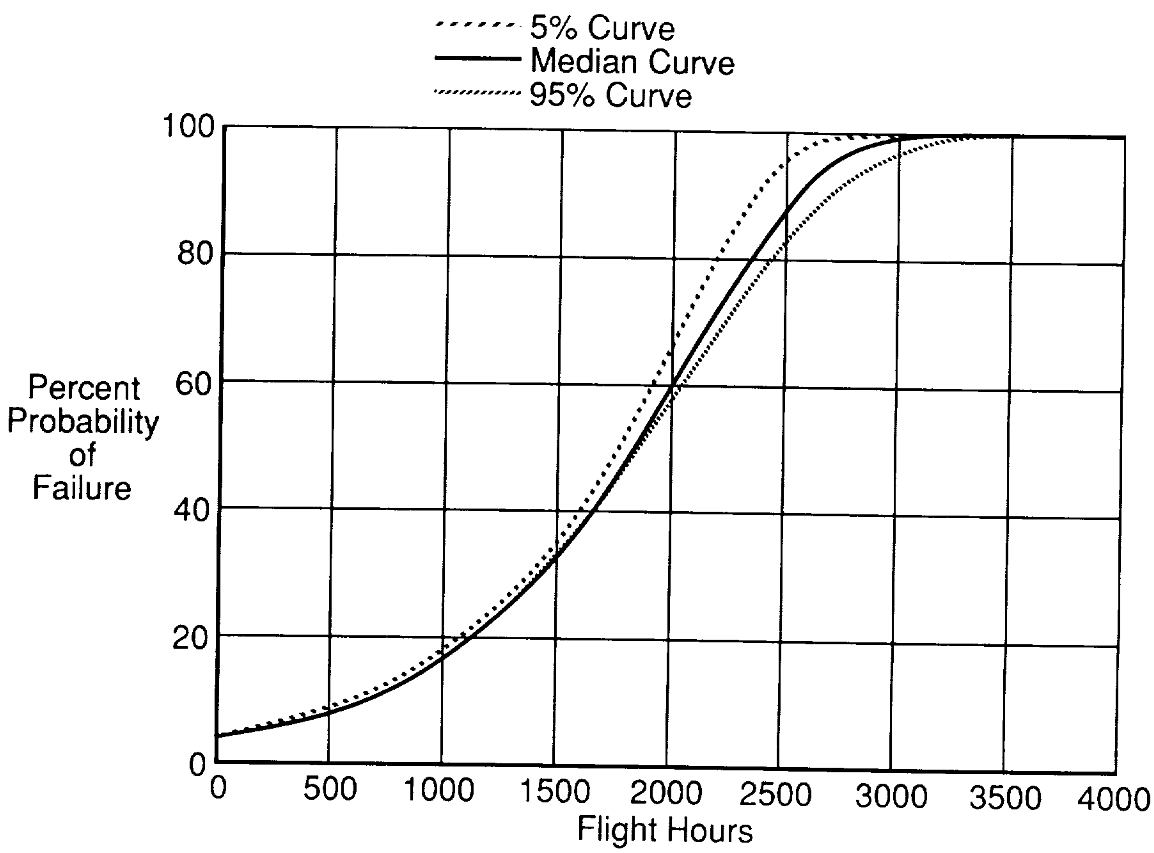

Figure 7

A SUBSEQUENT INSPECTION INCREASED THE DATA SET TO 181 AIRCRAFT WITH 12 FAILURES

Subsequent inspection data increased the sample to 181 aircraft containing 12 aircraft with failures. Again this information was plotted and Weibull distributions determined for the median, five percent, and ninety five percent rank points. These curves are shown along with the result obtained by computing the confidence bands for the linear regression parameters. The two methods compare well, except at the lower end where the variation in the location parameter is felt more strongly.

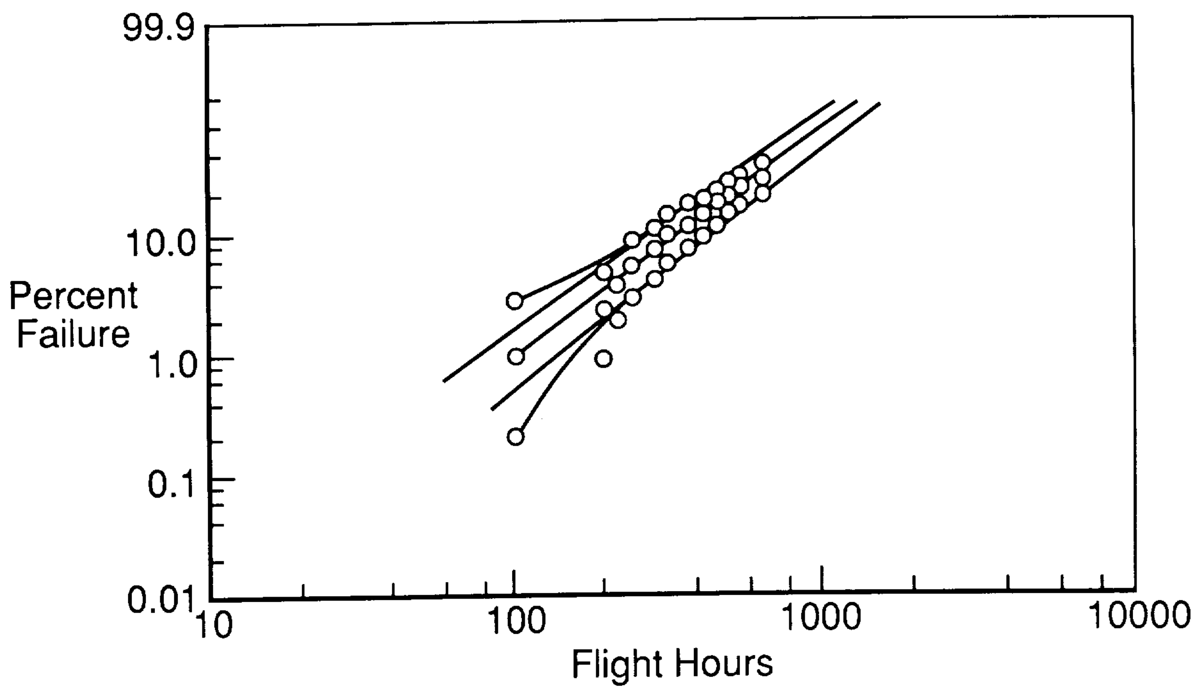

Figure 8

CUMULATIVE PROBABILITY OF FAILURE FOR SECOND DATA SET

The cumulative probability of failure for the second data set containing twelve failures is shown. Included on the plot is the 90% confidence band.

The 90% confidence band is much smaller than that with only six data points, especially at the high probability of failure, indicating that the data set now represents the actual behavior of the failure mechanism to a much higher degree than the original data set. The influence of the early failure has been reduced by the new data points, many of which fell between the first failure at 770 hours and the second failure at 1035 hours in the original set of data.

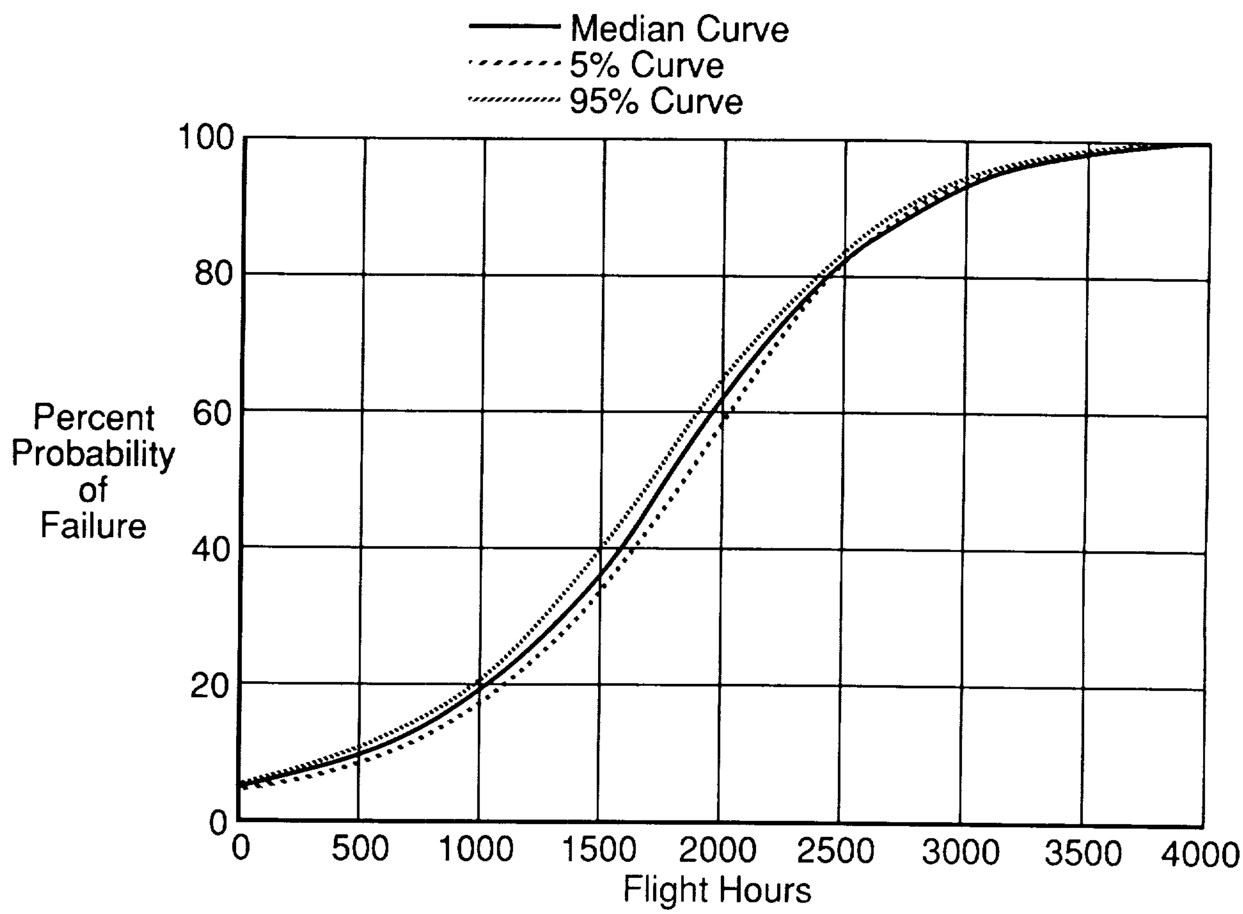

Figure 9

AREAS OF CONTINUING EFFORT

We are continuing our effort in several areas. We will implement a Maximum Likelihood Estimation (MLE) process to determine the Weibull parameters. An iterative procedure is required; however, our experience with the MLE process for two-parameter Weibull curvefits indicates that convergence is very rapid. The linear regression process we are currently using weighs all the points equally in their effect on the regression line, whereas the MLE process weighs the analysis toward the bulk of the data.

The process of projecting cracks to their critical level is accomplished deterministically from the crack growth curve. The crack growth process is, in fact, a random process and thus there is some uncertainty associated with the actual lives at failure. Inspection data is also treated deterministically. Nondestructive Evaluation (NDE) techniques have some uncertainty associated with their ability to detect flaws. The uncertainty, or randomness, of these two phenomena should be included. This uncertainty is best addressed using a Monte Carlo technique at the cost of some additional computation time. The advantage is that we will receive a better picture of the actual risk.

Our current process does not account for the repair of cracked parts and the return of the aircraft to service. We are looking to Renewal Analysis techniques to provide an assessment of such repairs. Repaired aircraft are of particular interest to fleet commanders in planning allocation of resources and logistic needs and to project the maintenance and repair actions required with continued fleet usage.

Maximum Likelihood Estimation of Weibull Parameters

Monte Carlo Simulation Will Allow:

- **Random Crack Growth Characteristics**
- **Uncertainty in Inspection Data**

Renewal Analysis to Account for Replacement of Failed Components

Figure 10

REFERENCES

1. Christian, T.F., Smith, H.G., and Saff, C.R., "Structural Risk Assessment Using Damage Tolerance Analysis and Flight Usage Data", ASME WAM, 7-9 December 1986, Anaheim California.

2. Saff, C.R., Smith, H.G., and Christian, T.F., "Applications of Damage Tolerance Analysis to Structural Risk Assessment", AIAA/ASME/ASCE/AHS 25th Structures, Structural Dynamics and Materials Conference, 6-8 April 1987, Monteray California.

3. Pinckert, R.E., "Damage Tolerance Assessment of F-4 Aircraft", AIAA Paper No. 76-904, Sept. 1976.